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# QA Testing of Si Diodes

Jim Dowd

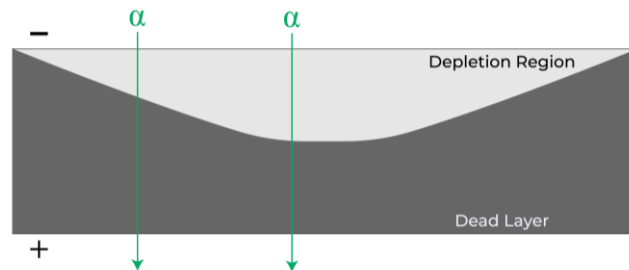
Nov 8, 2021

# Dead Layer

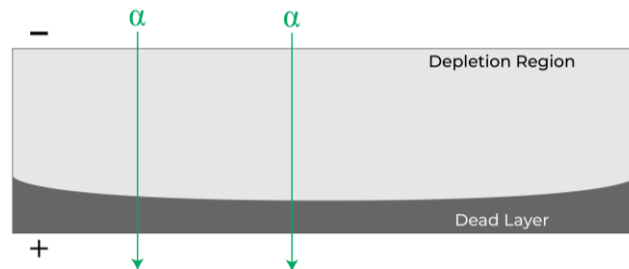
*Electrically non-responsive region outside of depletion region*

- Concerns about large dead layers in poor quality diodes
  - Unpolished backs
  - State of dead layer unknown
- Large dead layers reduce energy resolution of detector
  - Energy loss is not measurable for particles with unknown energies
  - Stacked diode configuration compounds uncertainty
- Determine bias voltage needed for full depletion
  - Characterization and measurement of dead layer
  - Incremental variations in bias setting to optimize configuration
  - Dead layer is minimized at optimum bias voltage

Partially Depleted Detector

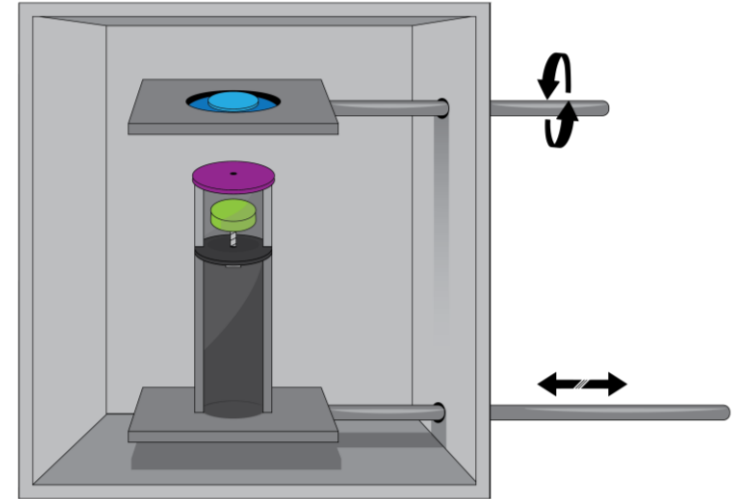


Fully Depleted Detector



# Procedure

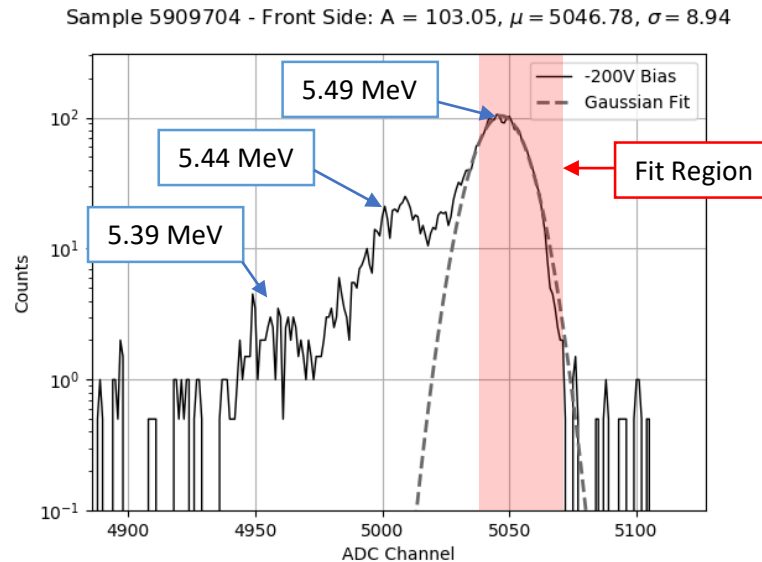
- Designed and constructed vacuum chamber
  - Collaborated with a mechanical engineer for custom components
- Measured ADC response with nominal reverse bias voltage
  - Reference measurement
    - -200 V bias
    - Alpha particles incident on front of detector
- Measured ADC response at 10 V increments
  - -150 V to -250 V bias
  - Alpha particles incident on back face of detector



AM-241 Source  
Collimator  
Si Diode

# Analysis

- Apply Gaussian fit to each response curve
  - Only applied around highest peak and falling edge of distribution
- Mean of Gaussian
  - ADC channel of primary  $\alpha$ -energy
- Front Face
  - Negligible dead layer
  - Three main Am-241 peaks are distinct
- Back Face
  - Undefined dead layer
  - Three main Am-241 peaks are smeared together



# Linearity of Response

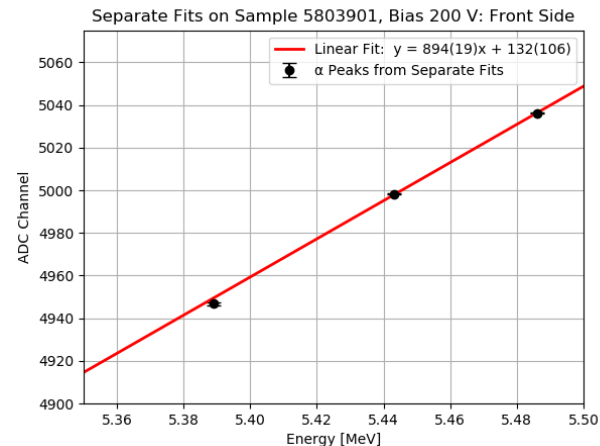
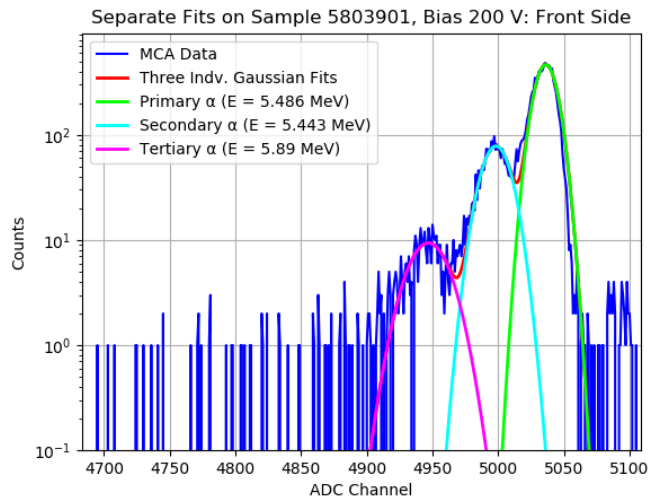
- 24 hr measurement for maximum peak differentiation
- Gaussians were fit to three main Am-241  $\alpha$ -peaks
- Linear fit applied to the mean values

Linear fit is just over one standard deviation from passing through origin

$$y = 894(19) \frac{\text{Channels}}{\text{MeV}} x + 132(106) \text{Channels}$$

- Channel 0 = 0 MeV

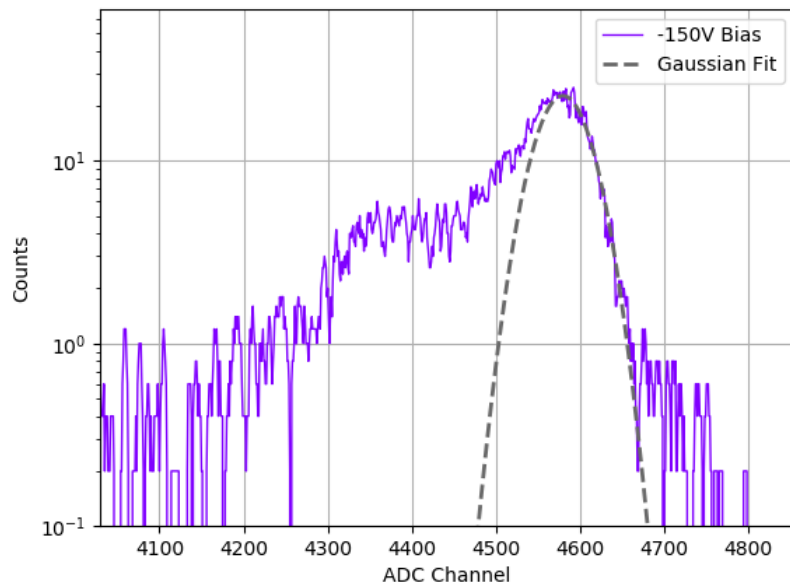
Reasonable Approximation!



# Back Face: -150 V Bias

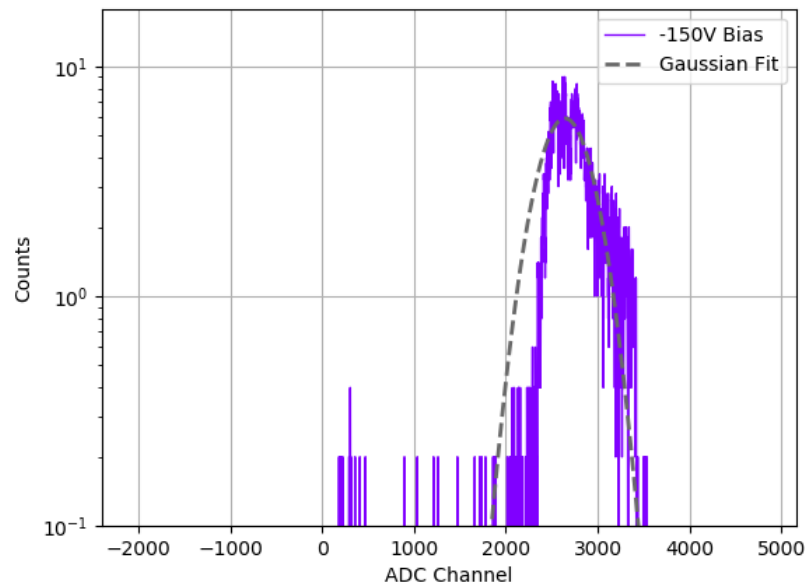
## Example of Best

Sample 5909704 - Back Side:  $A = 22.69$ ,  $\mu = 4579.40$ ,  $\sigma = 30.56$



## Example of Worst

Sample 5904749 - Back Side:  $A = 5.94$ ,  $\mu = 2643.90$ ,  $\sigma = 280.14$

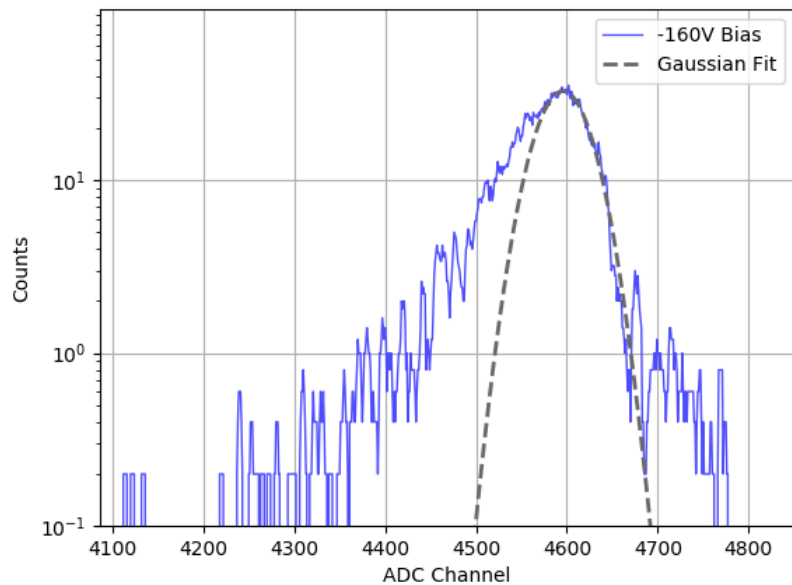




# Back Face: -160 V Bias

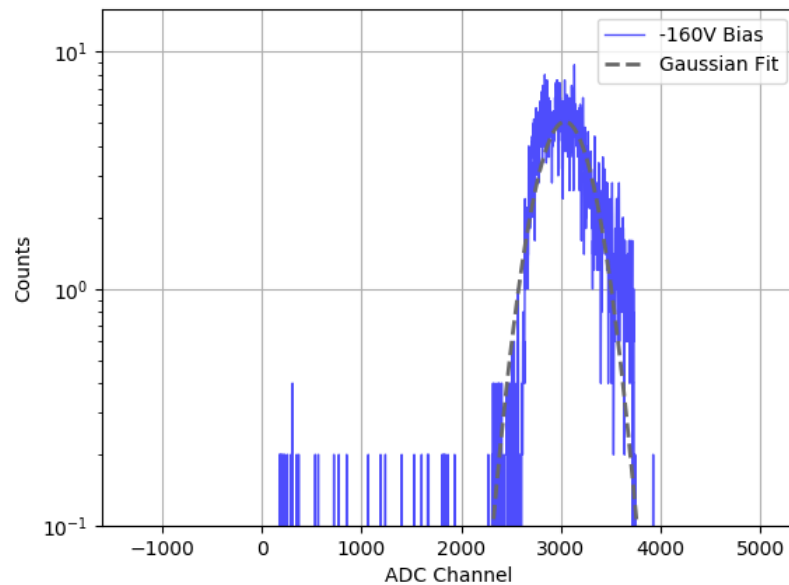
## Example of Best

Sample 5909704 - Back Side:  $A = 32.69$ ,  $\mu = 4595.64$ ,  $\sigma = 28.29$



## Example of Worst

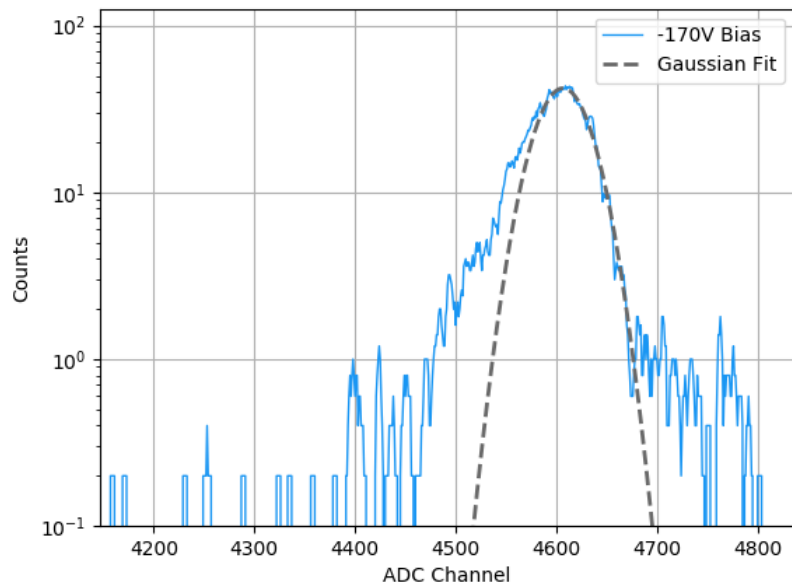
Sample 5904749 - Back Side:  $A = 5.07$ ,  $\mu = 3040.00$ ,  $\sigma = 258.13$



# Back Face: -170 V Bias

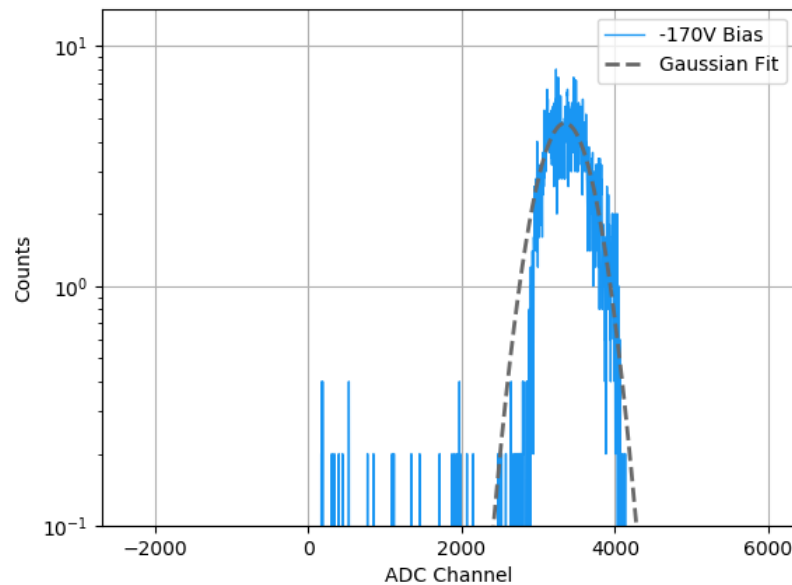
## Example of Best

Sample 5909704 - Back Side:  $A = 42.06$ ,  $\mu = 4606.56$ ,  $\sigma = 25.55$



## Example of Worst

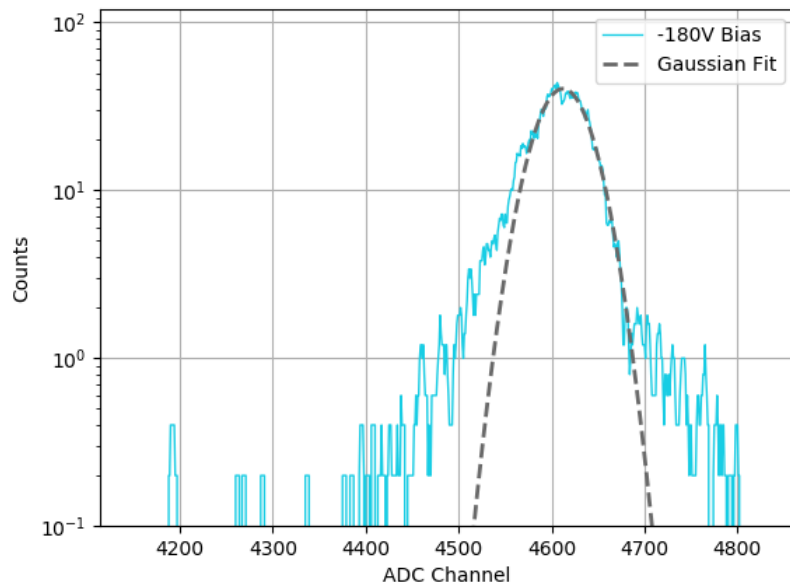
Sample 5904749 - Back Side:  $A = 4.77$ ,  $\mu = 3347.94$ ,  $\sigma = 335.57$



# Back Face: -180 V Bias

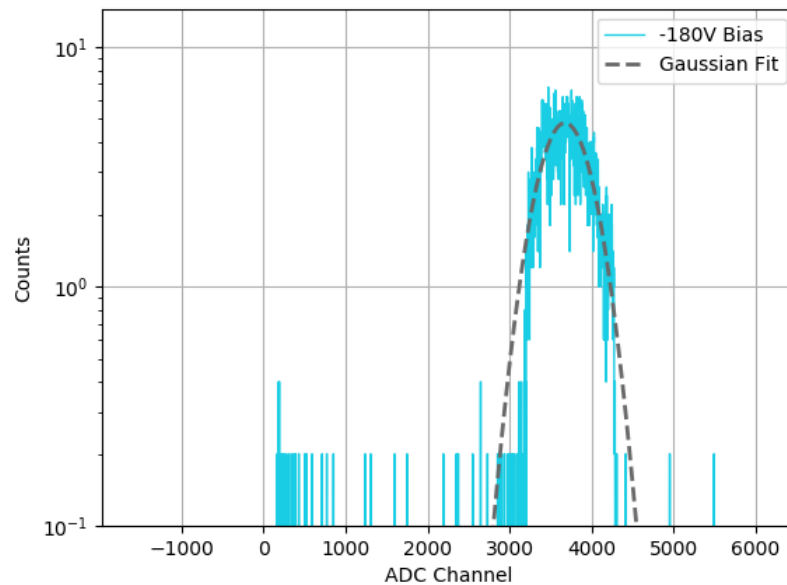
## Example of Best

Sample 5909704 - Back Side:  $A = 40.26$ ,  $\mu = 4612.15$ ,  $\sigma = 27.67$



## Example of Worst

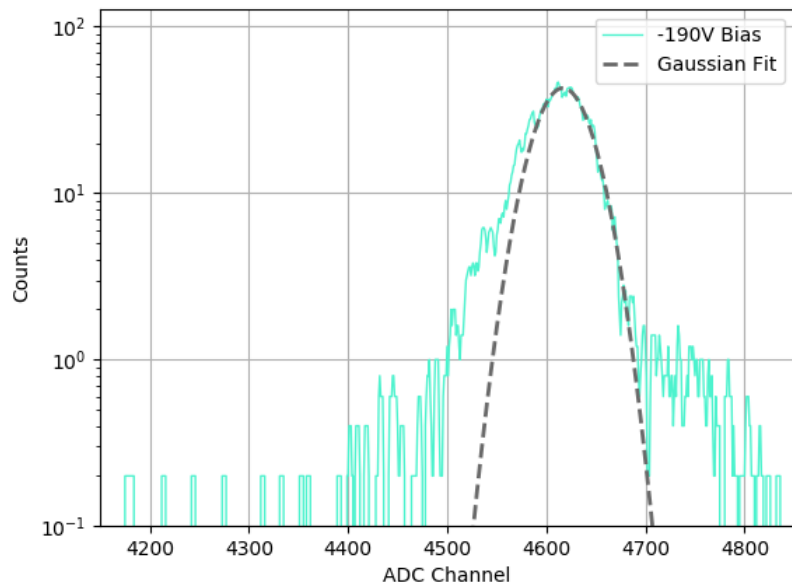
Sample 5904749 - Back Side:  $A = 4.82$ ,  $\mu = 3674.16$ ,  $\sigma = 313.38$



# Back Face: -190 V Bias

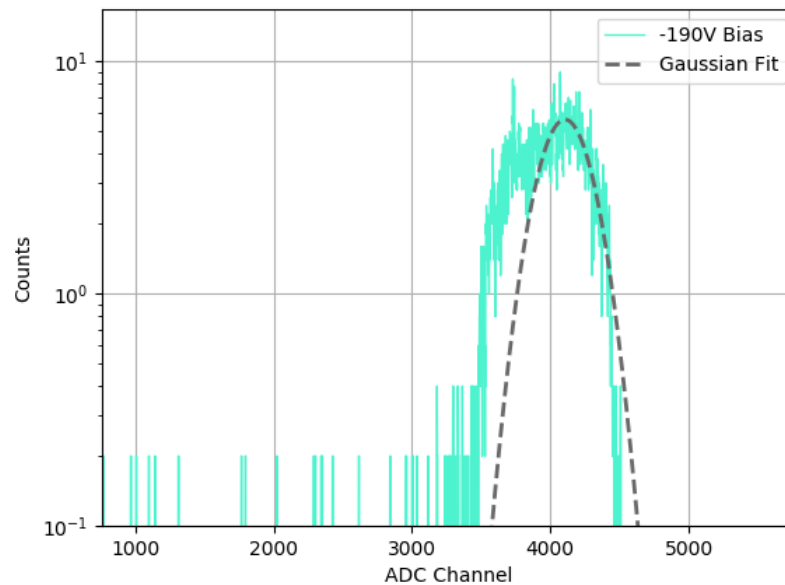
## Example of Best

Sample 5909704 - Back Side:  $A = 42.73$ ,  $\mu = 4616.78$ ,  $\sigma = 25.95$



## Example of Worst

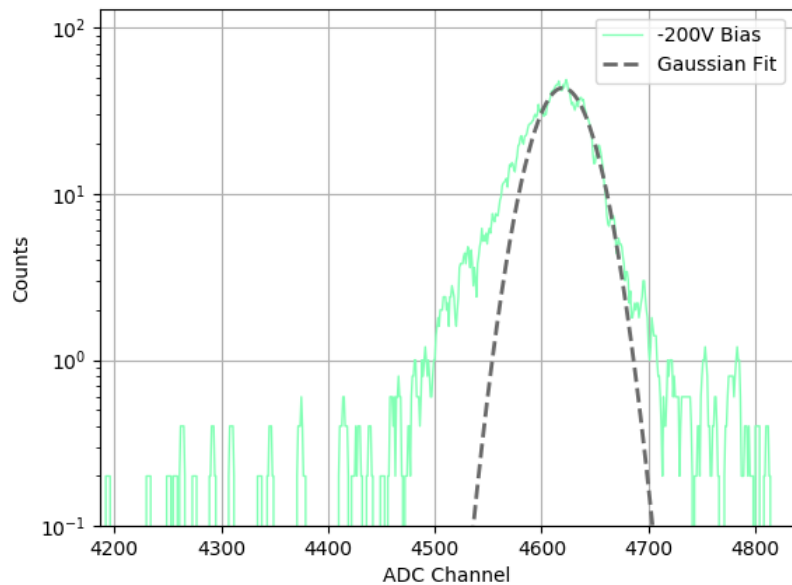
Sample 5904749 - Back Side:  $A = 5.63$ ,  $\mu = 4105.46$ ,  $\sigma = 185.89$



# Back Face: -200 V Bias

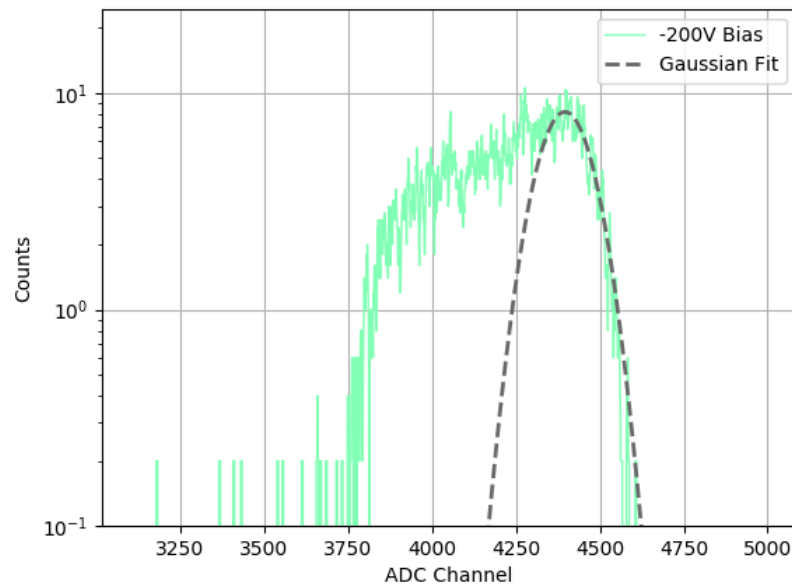
## Example of Best

Sample 5909704 - Back Side:  $A = 43.51$ ,  $\mu = 4619.88$ ,  $\sigma = 24.07$



## Example of Worst

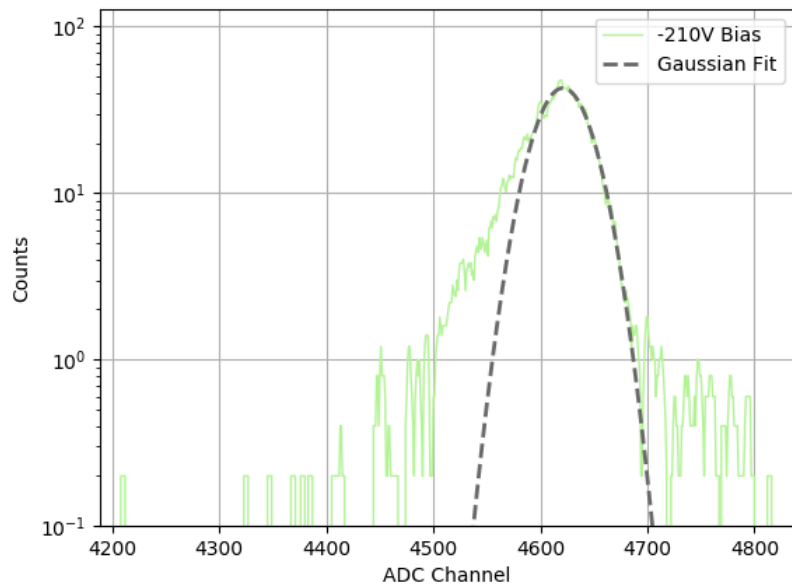
Sample 5904749 - Back Side:  $A = 8.19$ ,  $\mu = 4395.84$ ,  $\sigma = 76.63$



# Back Face: -210 V Bias

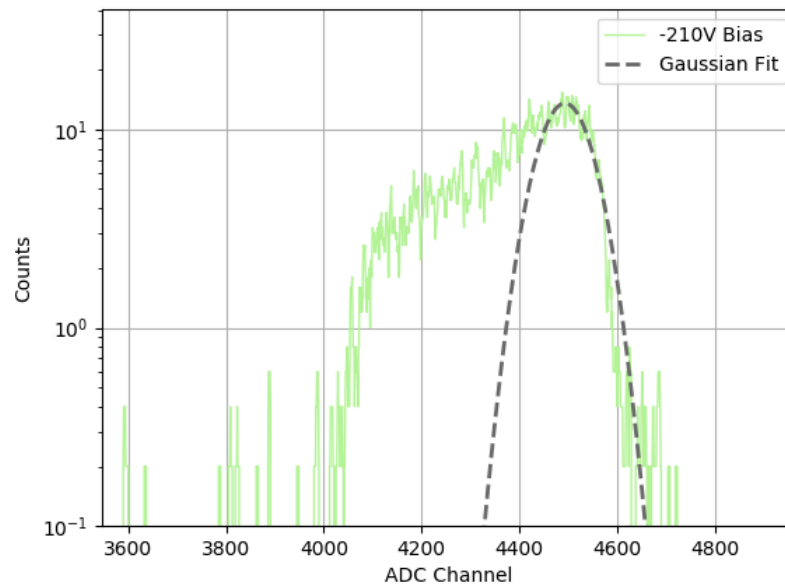
## Example of Best

Sample 5909704 - Back Side:  $A = 42.76$ ,  $\mu = 4621.04$ ,  $\sigma = 24.03$



## Example of Worst

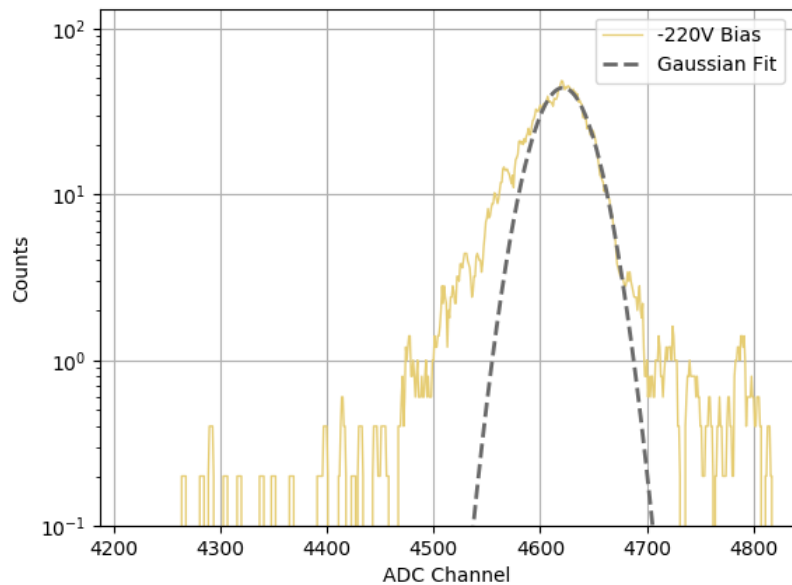
Sample 5904749 - Back Side:  $A = 13.54$ ,  $\mu = 4493.19$ ,  $\sigma = 52.59$



# Back Face: -220 V Bias

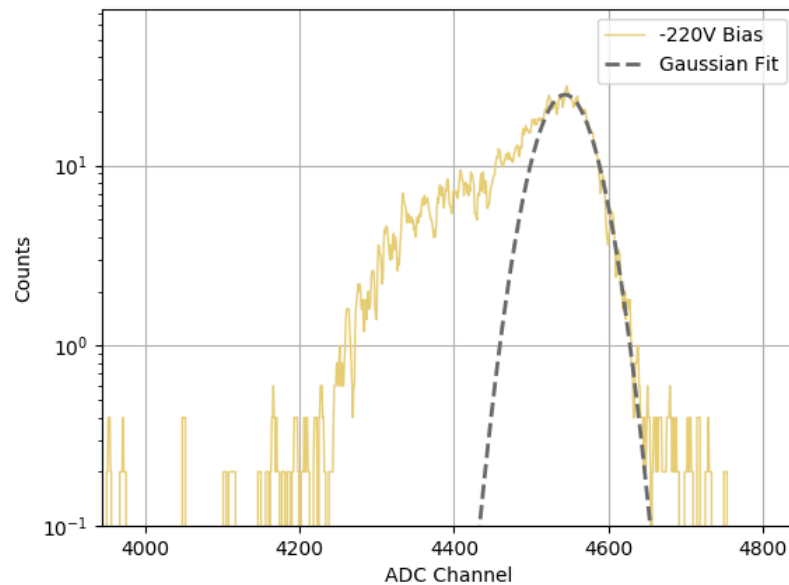
## Example of Best

Sample 5909704 - Back Side:  $A = 43.87$ ,  $\mu = 4621.27$ ,  $\sigma = 24.10$



## Example of Worst

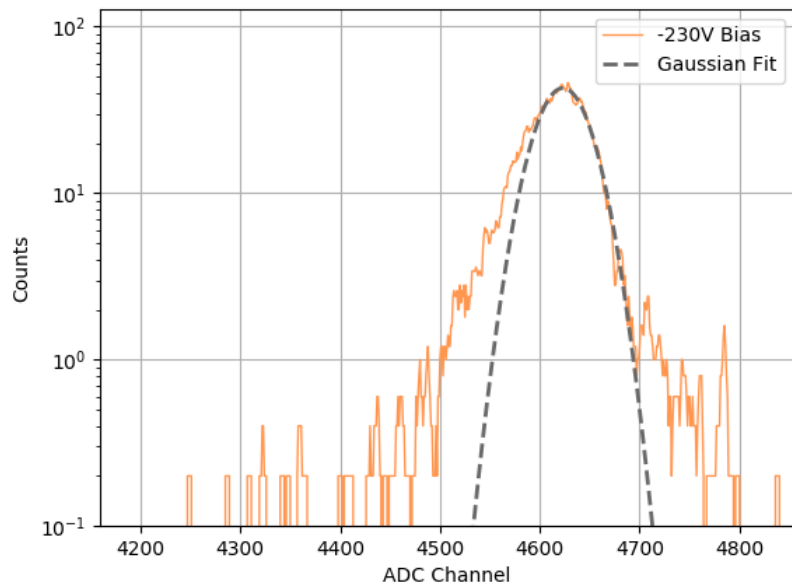
Sample 5904749 - Back Side:  $A = 24.68$ ,  $\mu = 4543.95$ ,  $\sigma = 33.34$



# Back Face: -230 V Bias

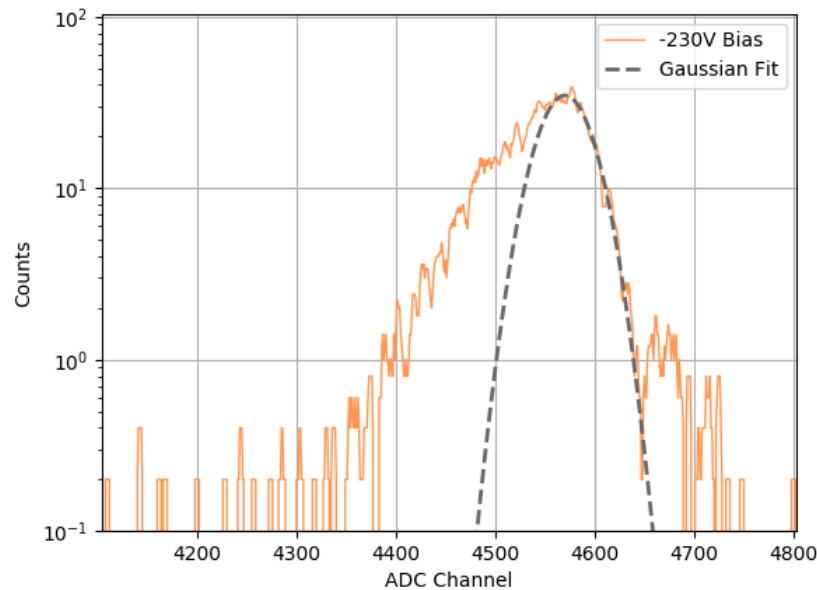
## Example of Best

Sample 5909704 - Back Side:  $A = 42.79$ ,  $\mu = 4623.13$ ,  $\sigma = 25.76$



## Example of Worst

Sample 5904749 - Back Side:  $A = 34.71$ ,  $\mu = 4570.03$ ,  $\sigma = 25.87$

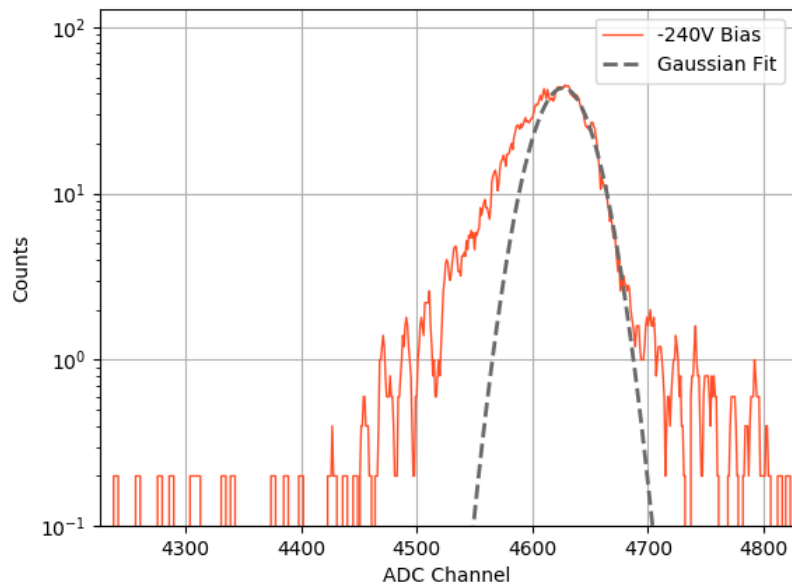




# Back Face: -240 V Bias

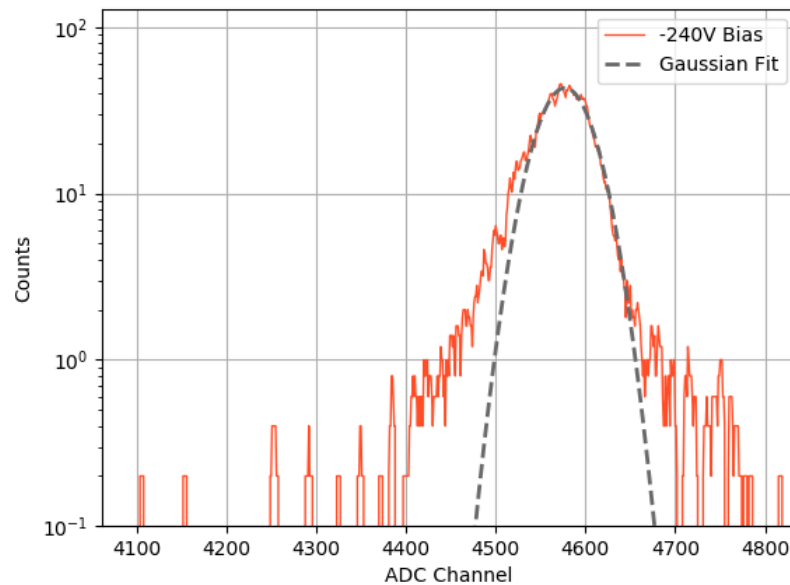
## Example of Best

Sample 5909704 - Back Side:  $A = 43.12$ ,  $\mu = 4626.40$ ,  $\sigma = 22.23$



## Example of Worst

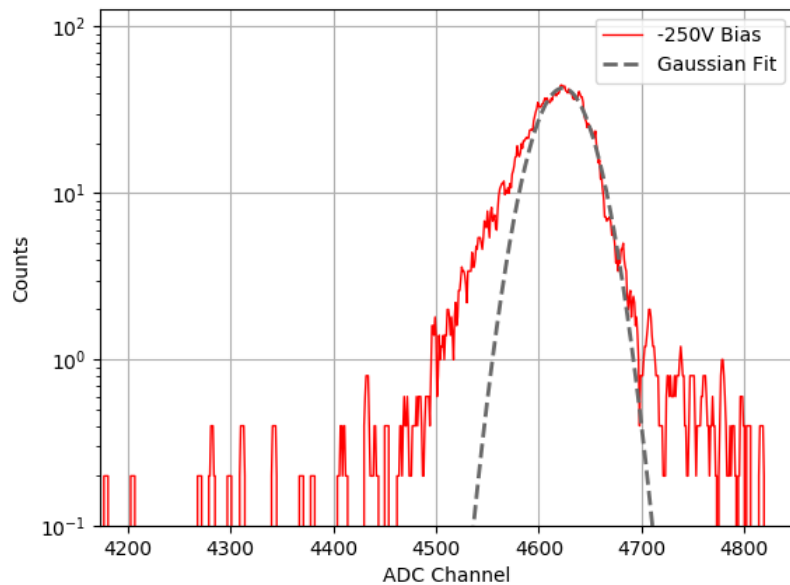
Sample 5904749 - Back Side:  $A = 43.14$ ,  $\mu = 4577.14$ ,  $\sigma = 28.64$



# Back Face: -250 V Bias

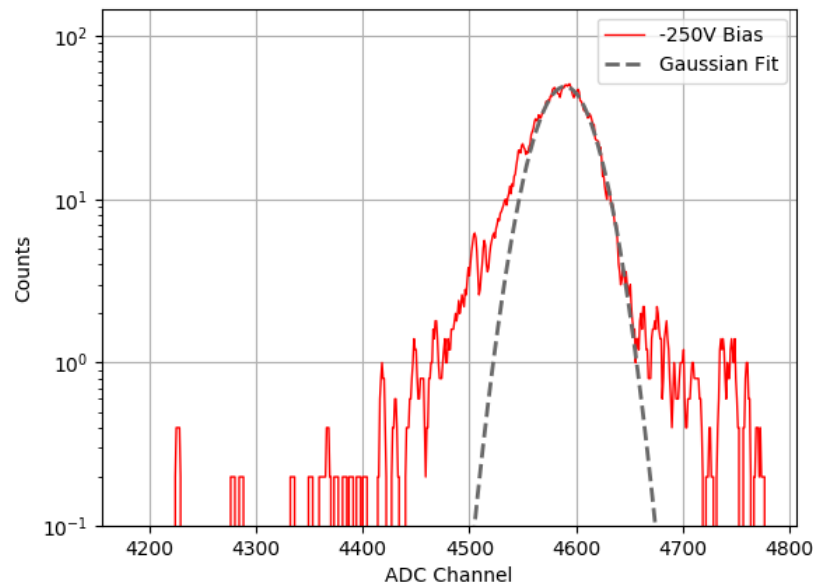
## Example of Best

Sample 5909704 - Back Side:  $A = 42.76$ ,  $\mu = 4623.42$ ,  $\sigma = 25.02$



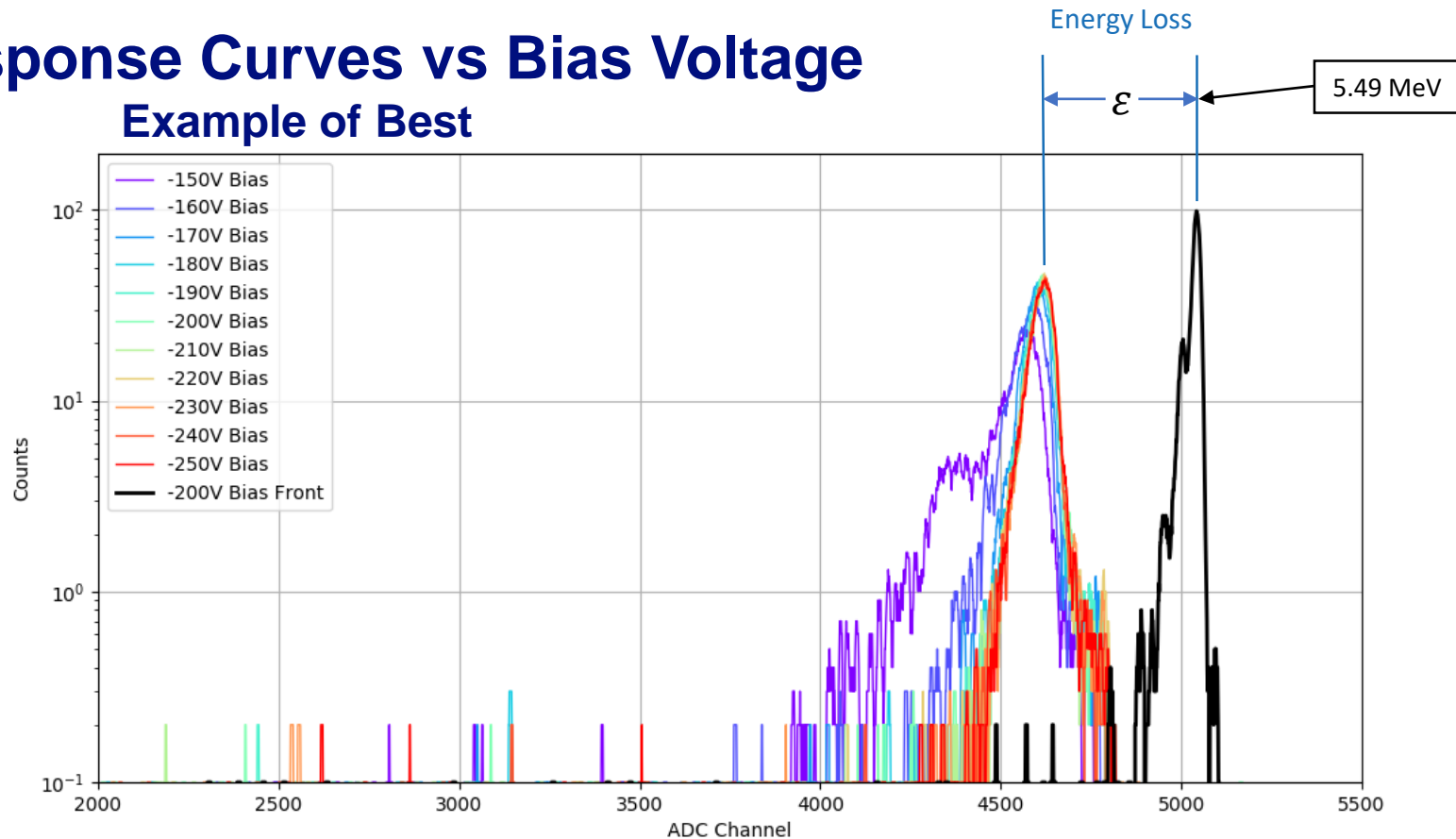
## Example of Worst

Sample 5904749 - Back Side:  $A = 48.84$ ,  $\mu = 4589.64$ ,  $\sigma = 24.13$



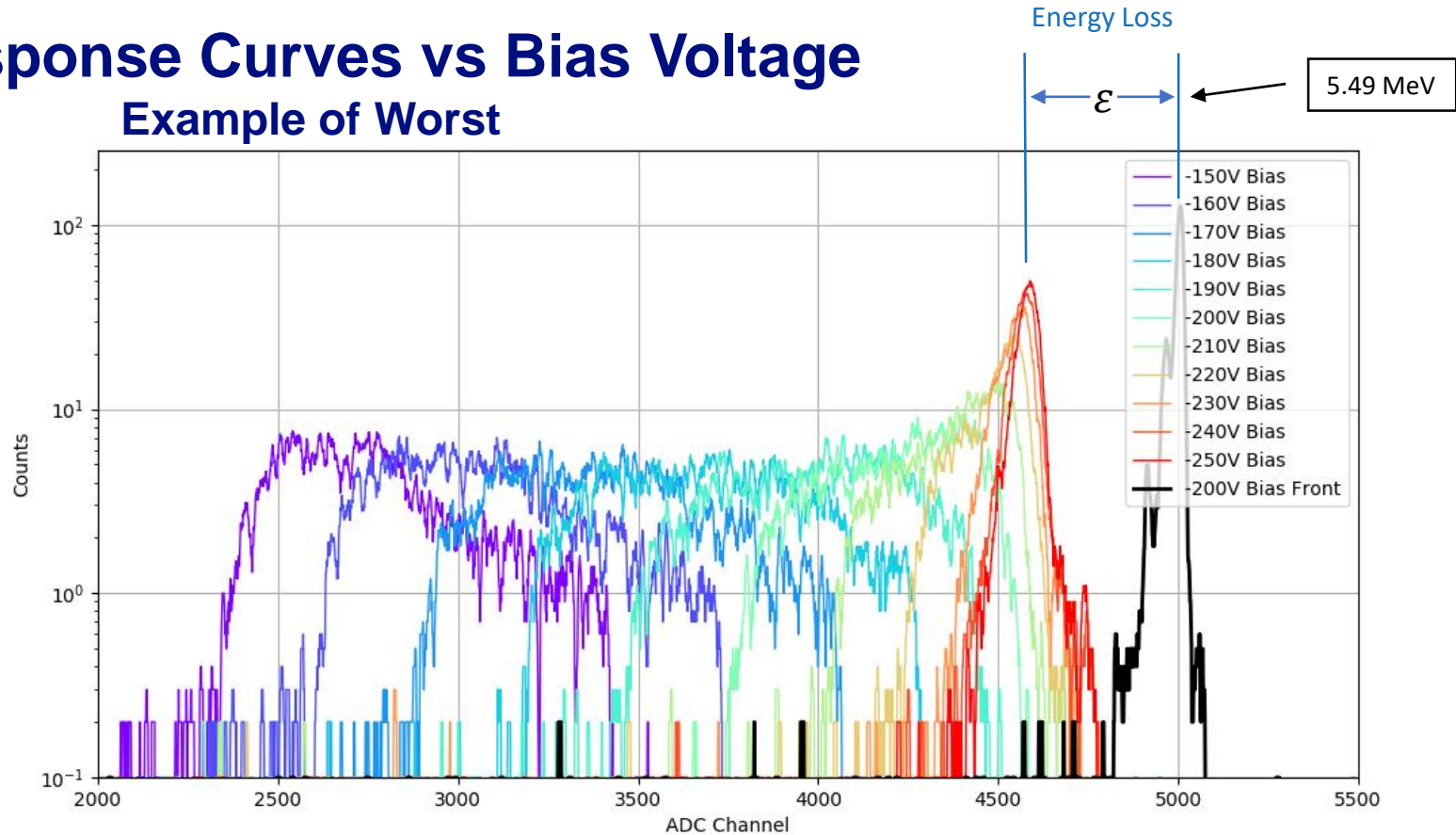
# Response Curves vs Bias Voltage

## Example of Best



# Response Curves vs Bias Voltage

## Example of Worst



## Analysis – cont.

- ADC gain is calculated from the reference measurement and is simple linear scaling:

$$f_{gain}^n = \frac{C_{ref}^n}{E_{\alpha}}$$

- Gaussian fits for each measurement scaled by the gain:

$$E_i^n = C_i^n f_{gain}^n$$

- Energy loss of the  $\alpha$  particle:

$$\varepsilon_i^n = E_{\alpha} - E_i^n$$

- Dead layer thickness is then:

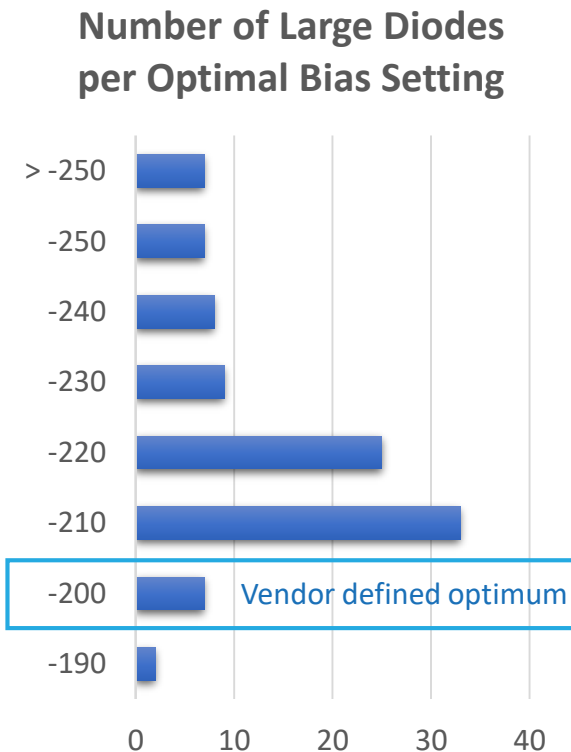
$$\Delta x_i^n = \frac{\varepsilon_i^n}{dE/dx}$$

$$dE/dx = 0.1336 \text{ MeV}/\mu\text{m}$$

$n$  = Sample number  
 $i$  = Bias voltage  
 $ref$  = Reference measurement  
 $C_i^n$  = ADC ch. of mean of Gauss. Fit  
 $E_{\alpha}$  = Energy of primary  $\alpha$   
 $E_i^n$  = Energy of largest peak  
 $\Delta x_i^n$  = Dead layer thickness  
 $dE/dx$  = Energy loss per distance

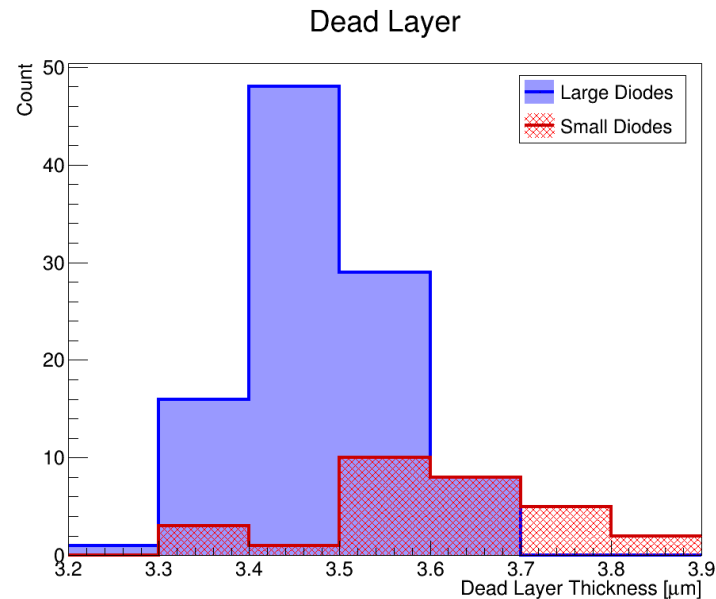
# Optimal Bias Setting Results

- Optimal bias conditions:
  - Response curve is approximately Gaussian
    - i.e. minimal tail on distribution
  - The mean of Gaussian fit stabilizes
- Inconsistent optimal bias voltage
  - Majority of diodes optimally biased to 210 or 220 V
  - Refutes vendor claim of 200 V
  - Some required  $\geq 270$  V



# Dead Layer Results

- Small dead layer relative to diode thickness ( $\sim 1\text{ mm}$ )
  - Mean =  $3.54\text{ }\mu\text{m}$  for large diodes
  - Mean =  $3.61\text{ }\mu\text{m}$  for small diodes
- Surprisingly consistent thicknesses
  - Large distribution of optimal bias settings
  - Large variations in response curve shapes below depletion



# Conclusions

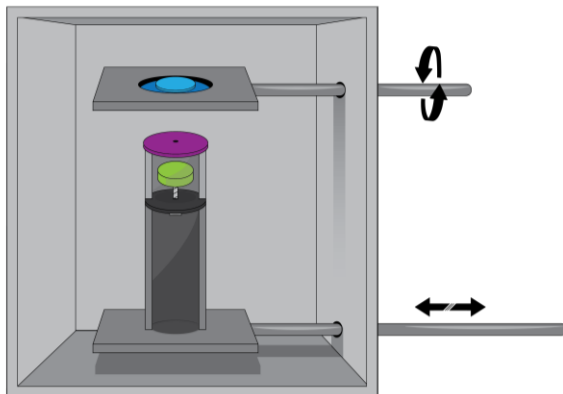
- Dead layers were small and consistent
- Diodes have an approximately linear energy response from 0 to 5.5 MeV
- Optimal bias setting showed large variation and differed from vendor claims
  - Did not correlate with dead layer or batch number
- Sufficient quantity of diodes were salvaged to meet near future needs
  - Now have time to find another vendor that can meet requirements



# Thank You

# Backup Slides

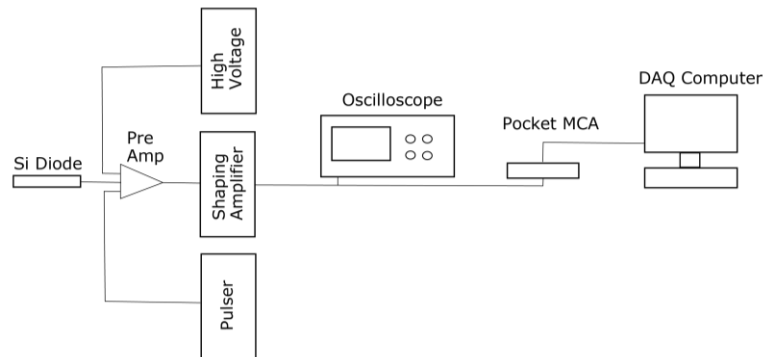
# Experimental Setup



## Apparatus

The Am-241 Source (Green) was collimated (Purple) and mounted on a linear actuator

Diodes (Blue) were mounted on rotational actuator, which allowed for measuring both sides without breaking vacuum



## Electronics

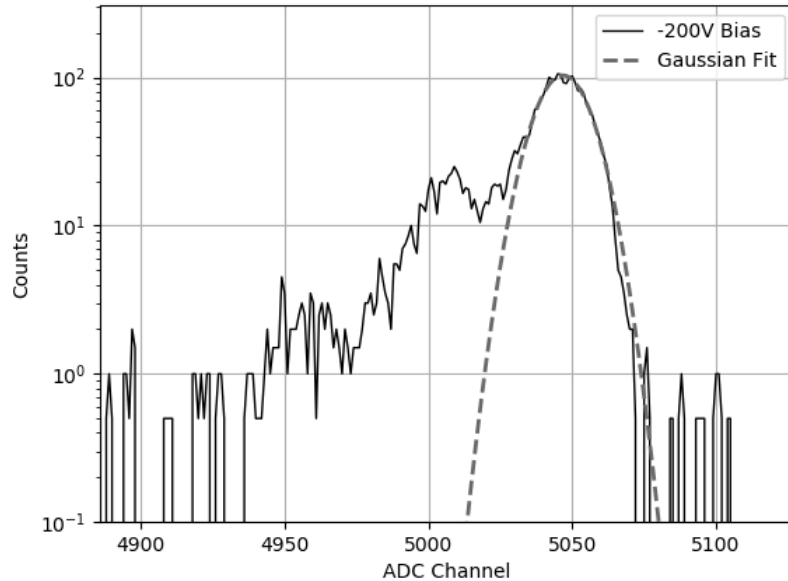
Output signal from diodes and a pulser signal were fed into the pre-amp

Pulser served as a check for drift in the gain, as well as, an indicator of the inherent noise in the system

# Front Face : -200 V Bias Reference Measurement

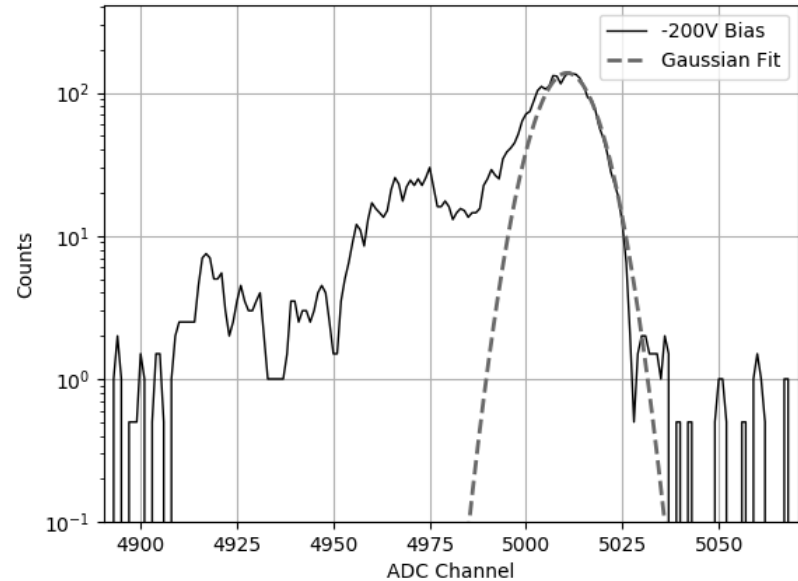
## Sample 5909704

Sample 5909704 - Front Side:  $A = 103.05$ ,  $\mu = 5046.78$ ,  $\sigma = 8.94$



## Sample 5904749

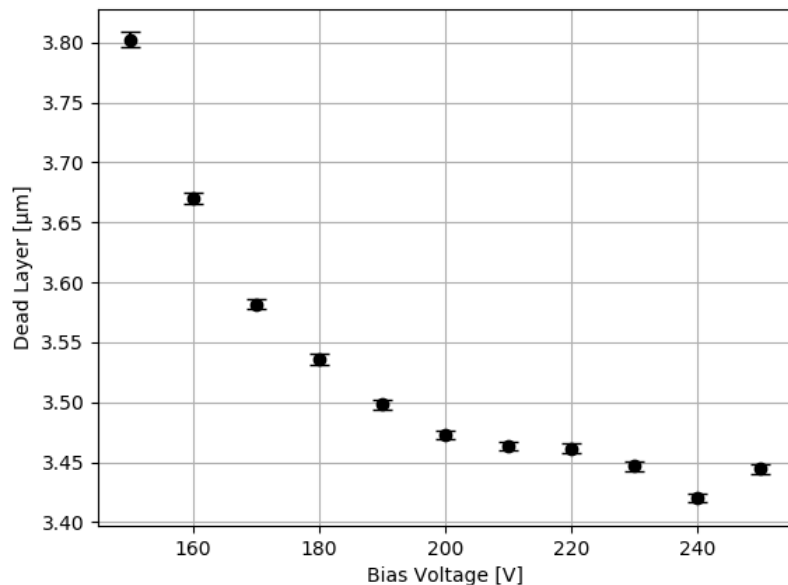
Sample 5904749 - Front Side:  $A = 137.48$ ,  $\mu = 5010.61$ ,  $\sigma = 6.67$



# Back Face: Dead Layer vs. Bias

## Sample 5909704

Sample 5909704 - Dead Layer



## Sample 5904749

Sample 5904749 - Dead Layer

